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Heat Recovery at Army Materiel Command (AMC) Facilities

by

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An initial study has been completed on heat recovery technologies for reducing Army process energy consumption. The objective of this work is fourfold: to identify, evaluate, install, and monitor industrial heat recovery projects at Army Materiel Command (AMC) sites. In this first phase, potential waste heat recovery projects were identified and evaluated at two of these sites—Radford Army Ammunition Plant and the Louisiana Army Ammunition Plant.

Several possible applications for heat recovery technology were found to merit further study. More detailed analyses were performed during preliminary visits to the two sites. Next, plant surveys and comprehensive process-energy studies were conducted to determine actual operating conditions of the processes identified as having the greatest potential for heat recovery. Flow, temperature, and flue gas composition were the primary measurements considered.

Systems showing the highest probability of favorable thermal and economic performance were selected for the next stage of assessment. Then, based on a cost analysis to ensure that the applications would be economical, final selection was made. A preliminary design was prepared for each system.

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Systems showing the highest probability of favorable thermal and economic performance were selected for the next stage of assessment. Then, based on a cost analysis to ensure that the applications would be economical, final selection was made. A preliminary design was prepared for each system.

A condensing heat exchanger was procured during FY87 and installed on a packaged boiler at the Louisiana Army Ammunition Plant. The heat recovery equipment capacity is sized to allow preheating of all makeup water. Additional hot water loads were identified, which should further improve the economics.

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FOREWORD

This work was performed for the U.S. Army Engineering and Housing Support Center (USAEHSC), under Operations and Maintenance, Army (OMA) Funding Authorization Document No. 87-080007 (November 1986), through the Facilities Technology Applications Test (FTAT) program. The USAEHSC Technical Monitor was Mr. B. Wasserman, CEHSC-FU.

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HEAT RECOVERY AT ARMY MATERIEL COMMAND (AMC) FACILITIES

1 INTRODUCTION

Background

The 1973 oil embargo triggered legislation mandating that Federal agencies take steps to combat waste of fossil fuels.¹ Executive Order 12003, issued in 1977, required all Government organizations to reduce facilities (buildings, not transportation) energy use per square foot by 20 percent from FY75 to FY85, with an additional 20 percent reduction by the year 2000.

The Army Materiel Command (AMC) uses about a quarter of the Army's facilities energy in fulfilling its large-scale mission of providing materiel support. In turn, about half of AMC's energy is process energy, which is expended in a vast complex of industrial facilities. AMC's process energy consumption has risen dramatically in recent years, largely in response to increased production orders at Army ammunition plants. This upward trend has made it very difficult for AMC to meet the goals of Executive Order 12003 and other mandates.

AMC is approaching this dilemma in two ways. First, the method by which energy goals are set is being investigated to determine if definitions and weighting parameters are realistic, given the AMC mission. This research has focused on determining the true magnitude of process energy requirements and the impact of production variables such as labor hours, weather, and production equivalents. The second action by AMC is development of an energy plan² that calls for implementation of energy-saving strategies such as heat recovery technologies.

Many of the plants and buildings comprising AMC's industrial facilities were designed in the days of lower energy costs and, as such, afford opportunities for incorporating energy recovery and conservation measures. Heat recovery technology is especially promising for these complexes because it harnesses a form of energy which previously was wasted and uses it to replace other purchased energy. Since this technology has not been used to a great extent in the past, a methodology is needed for evaluating, selecting, and implementing the different heat recovery systems at AMC sites.

Objective

The ~~fourfold~~ objective of this work is to:

1. Identify opportunities for using waste energy recovery technologies at AMC sites

¹E. T. Pierce, et al., *Fuels Selection Alternatives for Army Facilities*, Technical Report E-86/03/ADA177062 (U.S. Army Construction Engineering Research Laboratory, 1986).

²*Comprehensive Energy Plans, Fiscal Year 1985 to Present* (U.S. Army Materiel Command, 15 May 1985).

2. Evaluate the potential heat recovery applications and select a variety of promising candidates

3. Demonstrate these technologies in the field by installing them at selected AMC sites

4. Verify the resulting energy reductions through follow-up energy monitoring.

The objective of this report is to document initial efforts in this project--the identification and evaluation of several different heat recovery applications at AMC facilities.

Approach

Two AMC sites were selected for study based on a review of documents describing their energy use patterns. The two sites were Radford Army Ammunition Plant (RAAP), Radford, VA, and Louisiana Army Ammunition Plant (LAAP), Shreveport, LA. A preliminary list of heat recovery applications suitable for more detailed analyses was compiled for each site during initial visits. Next, more comprehensive process energy studies were conducted at the two plants to determine actual operating conditions of the processes showing most promise for successful heat recovery applications. Flow, temperature, and flue gas composition were the primary variables measured.

A matrix approach was used to help organize the results for the different systems under study. As a result of this analysis, four systems were selected for more detailed evaluations, including a preliminary system design with overall system layout, physical interfaces with the existing process equipment, and the method of system control. The systems also were evaluated in terms of previous operating performance, maintainability, and reliability. Cost estimates were developed for all systems to ensure that the economics would be favorable enough to warrant installation; this analysis considered the first cost of all major components, installation, and annual operation and maintenance (O&M) costs. Two of the preliminary system designs were summarized as case studies for this report.

Mode of Technology Transfer

Information in this report will be used to expand technical expertise in the area of heat recovery applications for Army facilities. When a technology has been tested and proven successful over the long term, it will be recommended for implementation Army-wide through the appropriate criteria documents. Guidance also will be provided to help facilities engineers select and implement the system best suited to budget and operational considerations.

2 TECHNOLOGY ASSESSMENT AND PROJECT SELECTION

Heat Recovery Technologies--Overview

Waste heat can be embodied in several different sources at various temperatures, as Table 1* shows. These sources include both process and combustion heat, and may be dirty or corrosive, or relatively clean. In very large industrial complexes and somewhat smaller commercial/HVAC** systems, a portion of this waste heat can be recovered, improving energy efficiency. Heat recovery is achieved in a variety of ways, including use of heat exchangers and equipment such as turbines and compressors. Often, simple heat exchangers provide the most cost-effective method.³

A heat exchanger is a system that associates the heat stream (a gas or liquid source) and the fluid to be heated (another gas or liquid sink) in a way that permits heat transfer between them. Various names are used to describe these systems--recuperators, economizers, regenerators, waste heat boilers, condensers, heat pipes, and heat wheels.

A shell-and-tube heat exchanger often is used when two fluids at different pressures are to be contained for heat transfer. The higher pressure fluid is circulated in the tubes while the lower pressure fluid flows through the shell. Thus, when waste heat is contained in a vapor, it is usually inside this shell. Typical gas-to-liquid applications include economizers and condensing heat exchangers for use with boiler flue gas streams. Figure 1 shows an economizer. Condensing heat exchangers are similar to the economizer except that corrosion-resistant materials permit exhaust temperatures to be lower (discussed in more detail in Chapter 4). Often, the two devices are used in sequence. Other shell-and-tube applications include heat transfer from process liquids, condensates, and cooling water.

Two counterflow liquid-to-liquid devices, the plate-and-frame and the spiral heat exchangers, are shown in Figures 2 and 3. Figure 2 is an expanded view of a plate-and-frame exchanger with numerous plates that serve to increase the heat-transfer area and maximize exchanger effectiveness. Figure 3 is a schematic of a spiral heat exchanger. Hot fluid enters the center of the unit while the cold fluid enters at the top, and both fluids follow a spiral path through the exchanger until they are discharged either at the top (hot fluid) or center (cold fluid), respectively.

Another device for fluid-to-fluid applications (both gas-to-gas and liquid-to-liquid) is the heat-pipe heat exchanger. Heat-pipe exchangers are efficient, although expensive. Each pipe consists of a sealed element involving an annular capillary wick contained inside the full length of the tube, with an appropriate entrained fluid. Figure 4 shows how heat absorbed at the hot end evaporates the entrained fluid. Subsequently, the vapor delivers this latent heat to the cold end, where it is released during condensation. In a typical application, a bundle of the heat pipe elements extends between the source and sink.

Regenerators or air preheaters are gas-to-gas heat exchangers in the low to medium temperature range, and include heat wheels and passive gas regenerators.

*Figures and tables are at the end of each chapter.

**Heating, ventilating, and air-conditioning.

³K. G. Kreider and M. B. McNeil (Eds.), *Waste Heat Management Guidebook*, NBS Handbook 121 (National Bureau of Standards, 1977).

and building and swimming pool HVAC heat recovery. A heat wheel (Figure 5) consists of a large rotating disk of porous high-heat-capacity material that transfers waste heat between the gases in two parallel ducts. In some cases, the disk transfers moisture (latent heat) as well. A passive gas regenerator (Figure 6) is more costly but is less complex mechanically, and avoids possible cross-contamination. (Another alternative, when toxic or hazardous fumes are present, is to supply outside air locally to a booth or hood.)

Recuperators are also gas-to-gas heat-exchange devices and are used to recover heat from high-temperature furnace flue-gas streams to preheat process or combustion air. Typical applications include ovens and metal-working furnaces. Possible configurations include radiation recuperators, convection recuperators, and a combination of both types.

The radiation recuperator has an annular metal construction consisting of two concentric tubes through which the gases flow in parallel. This design is less efficient than other options in terms of heat transfer because it has less heat transfer area and a shorter residence time for the flue gases. However, it allows for a longer service life of the transfer materials since they are less likely to develop cold spots where acid condensation causes corrosion. The convection recuperator uses a shell-and-tube design, somewhat similar to a firetube boiler, as shown in Figure 7. This design usually provides greater heat transfer compared with the radiation recuperator, as well as a greater pressure drop. The tubes are made of either metal or ceramic material (e.g., the high-temperature ceramic recuperator). Figure 8 shows a combination radiation/convection configuration.

The heat engine is another device for energy recovery and often is purchased at a relatively high first cost. An example of a heat engine is the gas turbine, a rotating machine that transforms some of the energy in a fluid to rotary shaft energy. The fluid can be steam or other vapor (vapor-condensing turbine), hot gas (gas turbine), or compressed gas (expansion turbine). The sequence during which a working fluid is energized and deenergized is called a cycle; common cycles include the Otto cycle (used in the internal combustion engine) and the Rankine cycle.

Cycles can be "closed" or "open." In a closed-cycle system, the working fluid is reenergized (e.g., compressed and heated) and returned to its original state in a continuous loop, whereas in an open cycle, the fluid passes on to other uses or to discharge. A "combined cycle" system may include a series of several working fluids and several successive heat engine cycles (e.g., Brayton and Rankine).

The Rankine cycle characterizes several heat-transfer machines, including power station vapor-condensing turbines, heat pumps, and household refrigerators. A Rankine engine operates in four stages: (1) compression of the working fluid, (2) heating from liquid to a superheated state at fairly constant pressure, (3) expansion and partial condensation (which includes delivering work), and (4) heat delivery with completed condensation. In contrast, as Figure 9 demonstrates, a heat pump employs a reversed Rankine cycle to alternately cool or heat. An organic Rankine cycle (ORC) engine employs an organic working fluid such as freon (in place of steam) and can work with heat at moderate temperatures.

Analysis of Technologies

Commercially available heat recovery equipment includes both conventional and more advanced concepts and technologies. Examples of energy recovery technologies are absorbers, chillers, waste-heat boilers, conventional heat exchangers and economizers, condensing heat exchangers, high-temperature recuperators, and industrial heat pumps. These devices were evaluated for potential application at selected AMC facilities.

Table 2 is a matrix comparing the typical heat recovery technologies. Different criteria are presented to show their impact on system selection. Each category is ranked from 1 (poor) through 5 (best), based on the authors' judgment and on experience in industrial/commercial applications. Under this system, the best projects have the highest total score. No weighting of the individual criteria has been attempted. The principal criteria used in assessing these methods are explained below.

Technical Considerations

In examining the technical benefits of specific projects, the technical problems, associated benefits, and energy efficiency of each selected heat recovery technology must be considered. "Technical problems" include unresolved research issues, specific characteristics of the technology that affect proper function or service life, and maintenance problems that have been identified in operating systems. "Associated benefits" are those which are other than purely economical. For example, many of these technologies reduce pollution emissions (thermal or air) in addition to recovering waste heat. "Energy efficiency" refers to the efficiency with which the technology can recover waste heat. This benefit also impacts the economic criterion, but it is still important to consider the efficiency as an explicit property.

Economic Benefits

Three issues were considered as important in evaluating the economic benefits of specific projects: first cost, O&M expenses, and payback period. "First cost" refers not to the absolute cost of the heat recovery equipment, but to the cost of the equipment relative to that of the entire system from which energy will be recovered. For example, a recuperator's cost is typically a very large fraction of the total cost of the furnace on which it is installed. Condensing heat exchangers, on the other hand, account for only a small percentage of the total cost for diesel generator installation. Even though the two devices might have comparable payback periods, the condensing heat exchanger is likely to be more commercially acceptable than the recuperator simply because it is not as visible in a capital expenditure budget.

Not only installed costs, but also expected savings vary from one site to another and effect a wide range of payback periods. Savings are a function of hours of annual operation, as-found efficiency, and cost of fuel.

O&M expenses directly affect the economic desirability of heat recovery equipment. A "simple" payback period was used which ignores everything but first cost and net annual savings (which include O&M changes). Payback is the economic criterion most often considered by industrial managers in their initial evaluation of heat recovery systems. The projects studied for AMC facilities have a range of payback periods because installed costs are very site-specific. For example, a condensing heat exchanger may have a 2-year payback if retrofitted to a boiler with 78 percent overall thermal efficiency or a 6-year payback for a boiler with 84 percent efficiency.

Commercial Readiness

The stage of development, safety, and possible institutional issues associated with each project were considered under this criterion. Specific heat recovery technologies were rated as conceptual, laboratory prototype, field demonstration, commercially available from one or a few sources, or commonly available. Safety evaluations were based on site operational experience. Finally, institutional factors that influence these systems must be considered. For example, the potential for a particular technology to reduce production capacity, lower product quality, etc., must be examined carefully before an application is approved.

Range of Applications

This final category projects the number of applications for the technology at similar AMC facilities and how much energy can be saved at each site during the next 3 to 5 years. These elements measure the technology's capacity to save energy in the near term.

Site Visits and Project Selection

Early in the search for energy recovery opportunities, two AMC sites were selected (somewhat arbitrarily) and were visited to learn about their major plant operations and energy consumption patterns. Site personnel were interviewed for suggestions on possible heat recovery projects. This site survey identified potential conservation/housekeeping and equipment-based heat recovery measures. Both forms of energy reduction can compete for the same capital; since conservation often is the more cost-effective measure, the housekeeping tasks were recommended to be done first.

A potentially good heat recovery application is one that provides compatible waste heat sources and sinks that are spatially and temporally accessible to each other, and large enough to justify the economics of the recovery project. Based on the matrix scoring, several projects were selected as offering good potential for heat recovery at the selected AMC sites. Candidate projects were assessed for payback time; a "good" payback period is 3 to 5 years.

Final project selection involved a detailed technical and economic evaluation, including the specific technical issues and performance risks of each application. Chapters 3 and 4 summarize case studies for two of the AMC projects. These examples are representative of the evaluation/selection process used in the study; however, as noted earlier, the different applications are highly site-specific. Success of a particular technology at another facility must be evaluated on a case-by-case basis.

Table 1

Examples of Waste Heat Sources and Possible Heat Recovery Methods

Sources	Temperature (°F)	Potential Waste Heat Recovery (%)	Commercially Available Heat Exchangers
<u>Higher Temperature Waste Gases</u>			
Glass melting furnace	1800-2800	40-70	Recuperator
Chemical industry	1500-2800		- Ceramic
Fume incinerator	1200-2600		- Metal radiation
Fabricated metals	1500-2200		Heat wheel
Hydrogen plant	1200-1800		- Ceramic
Solid waste incinerator	1200-1800		Waste heat boiler
Steel heating furnace	1400-1500		Fluidized bed
<u>Medium Temperature Waste Gases</u>			
Annealing furnace cooling	800-1200	35-65	Recuperator
Catalytic cracker	800-1200		- Metal radiation/
Heat-treating furnace	800-1200		conduction
Gas turbine exhaust	700-1000		Heat wheel
Reciprocating engine exhaust	600-1100		- Metal
Drying and baking oven	450-1100		Air preheater
			Waste heat boiler
			Direct-contact
<u>Boiler Waste Heat Sources</u>			
Power boiler exhaust	450-900	30-65	Economizer
Process boilers (typical)	350-700		Air preheater
			Condensing
			Direct-contact
			Heat wheel
<u>Lower Temperature Heat Sources</u>			
Drying, baking, and curing ovens	200-450	30-60	Finned-tube
Hot processed solids	200-450		Plate-and-frame
Hot processed liquids	90-450		Spiral
Process steam condensate	130-190		Heat pipes
Liquid still condensers	90-190		Heat wheel
Cooling water (typical)	80-190		Air preheater
Air-conditioning and refrigeration condensers	90-110		

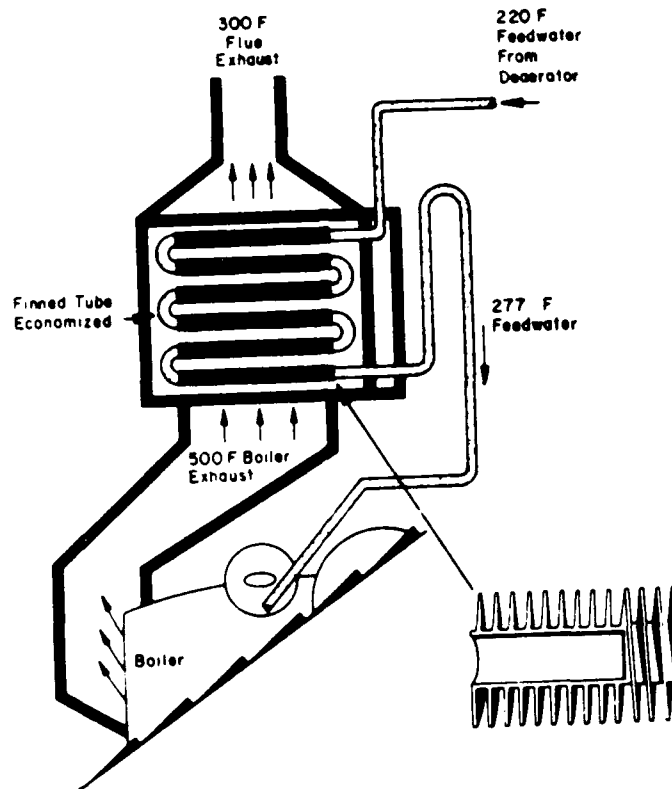


Figure 1. Finned-tube gas-to-liquid regenerator (economizer).

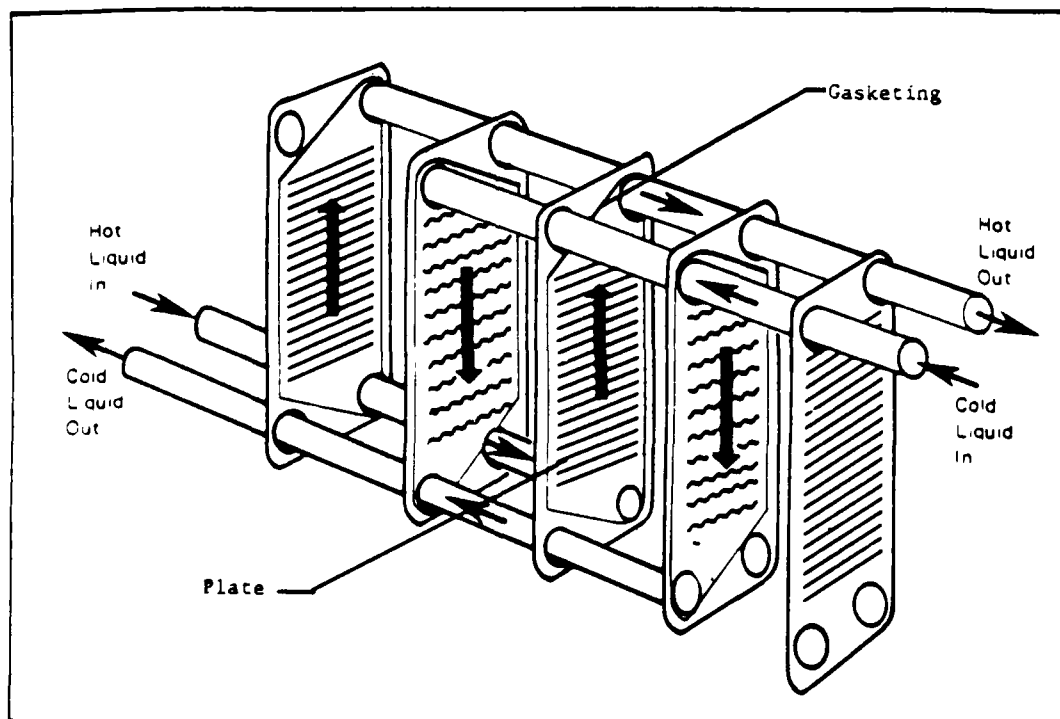


Figure 2. Plate-and-frame heat exchanger (expanded view).

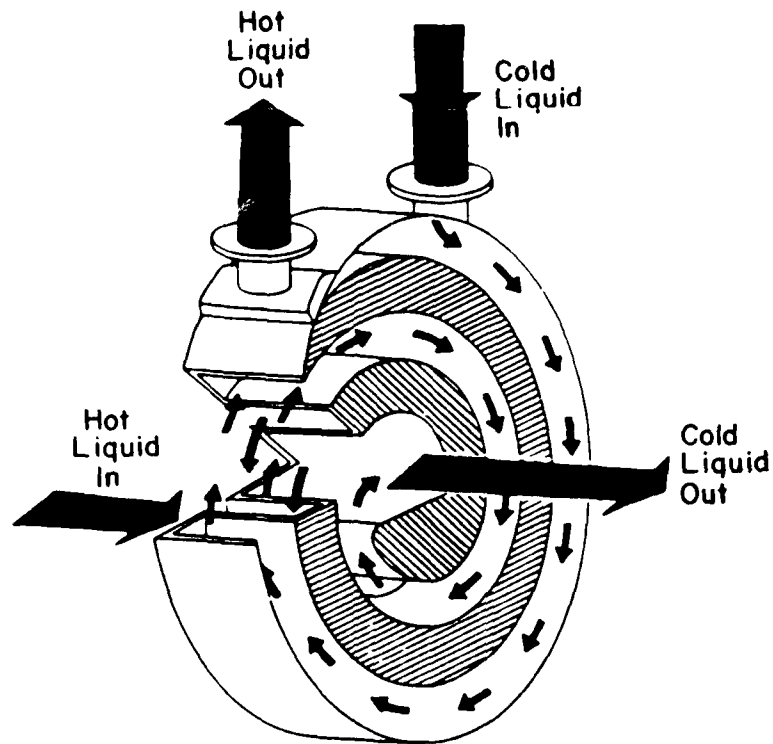


Figure 3. Spiral heat exchanger.

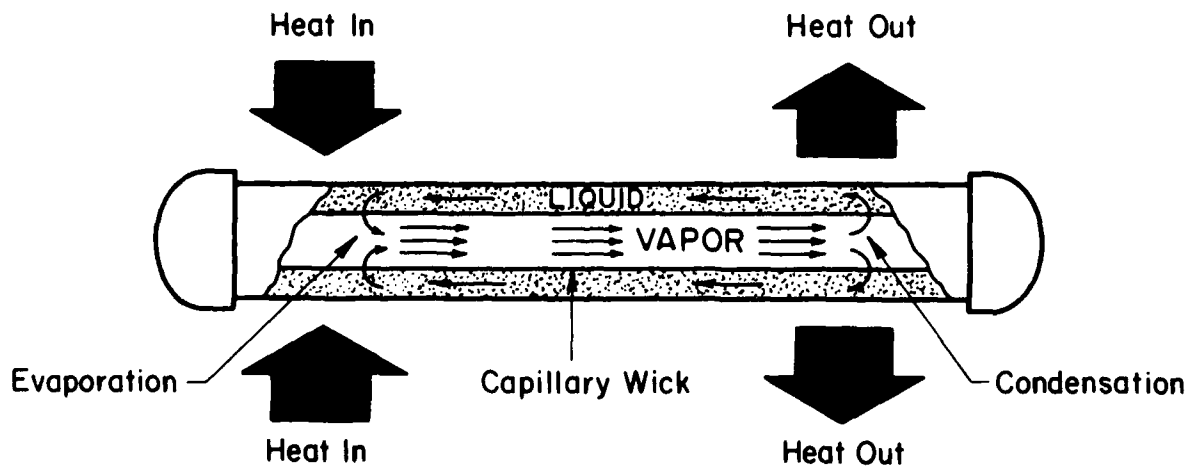


Figure 4. Heat pipe schematic.

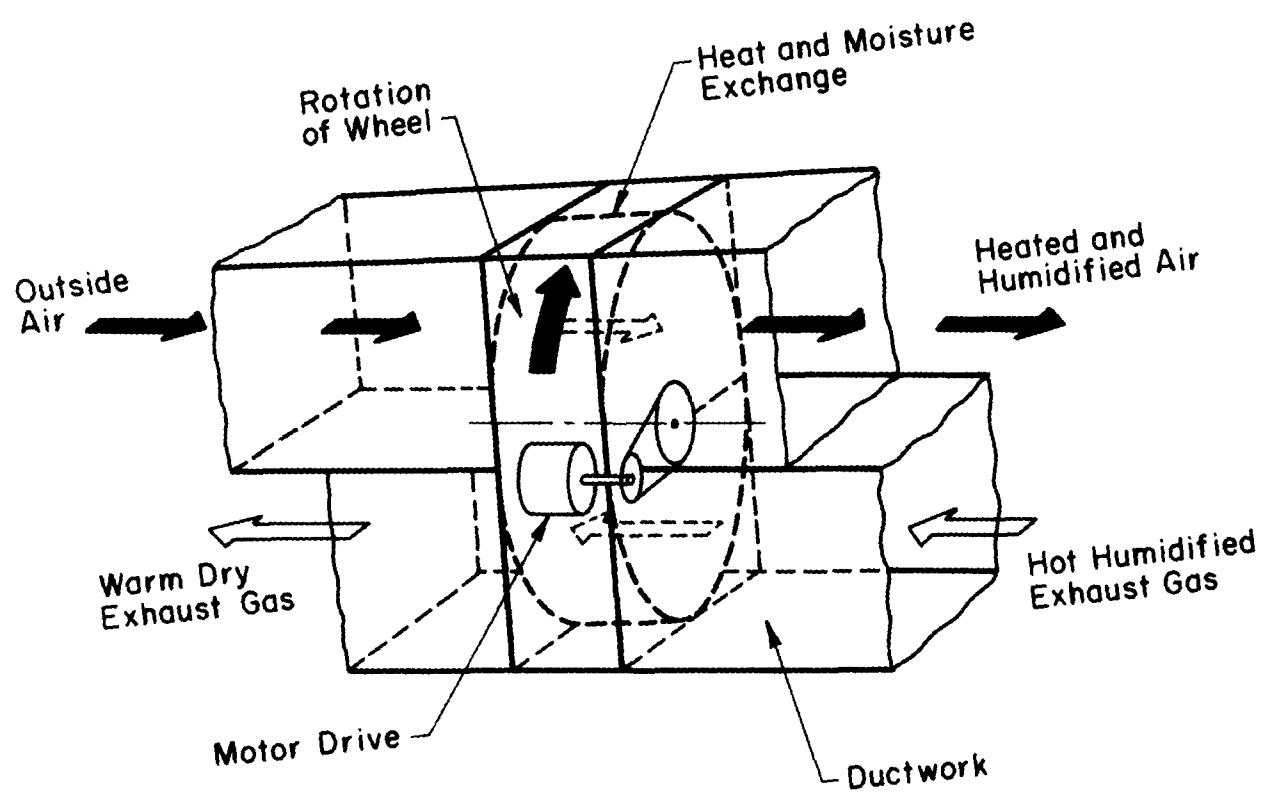


Figure 5. Heat and moisture recovery using a heat wheel regenerator.

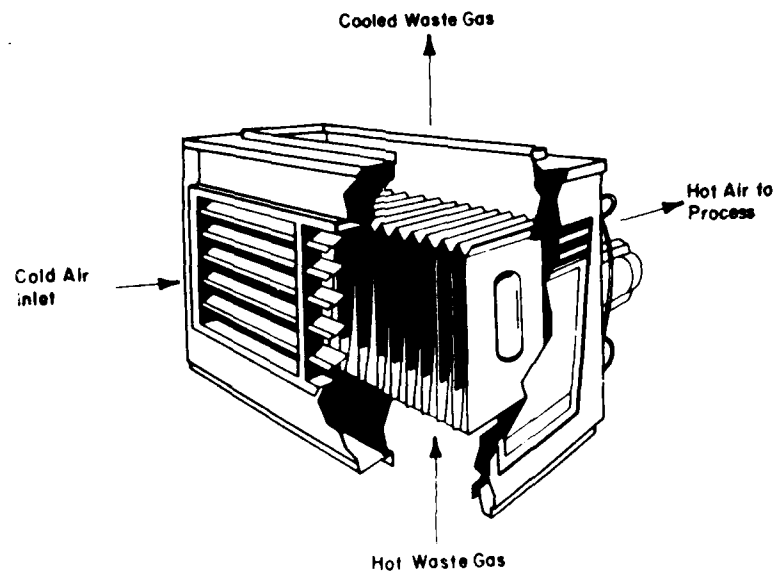


Figure 6. Passive gas-to-gas regenerator.

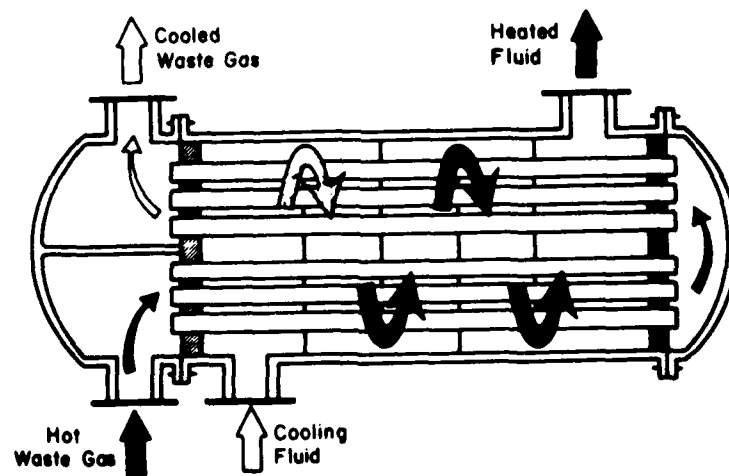


Figure 7. Convection recuperator.

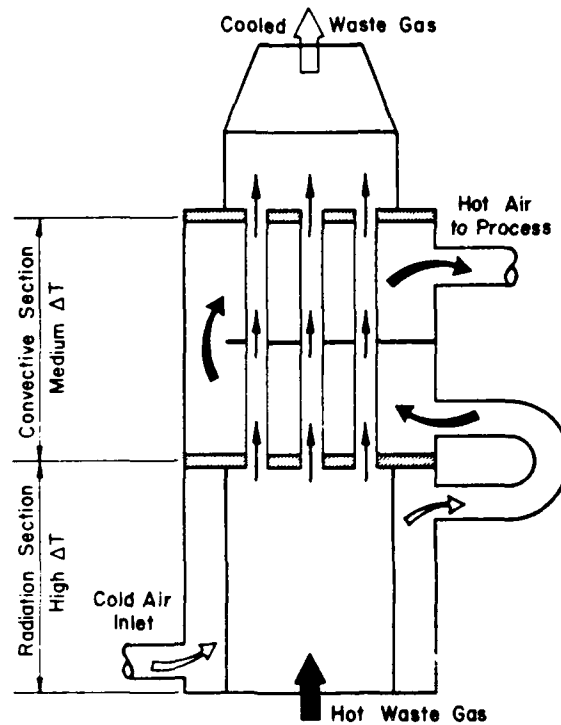


Figure 8. Combined radiation and convection recuperator.

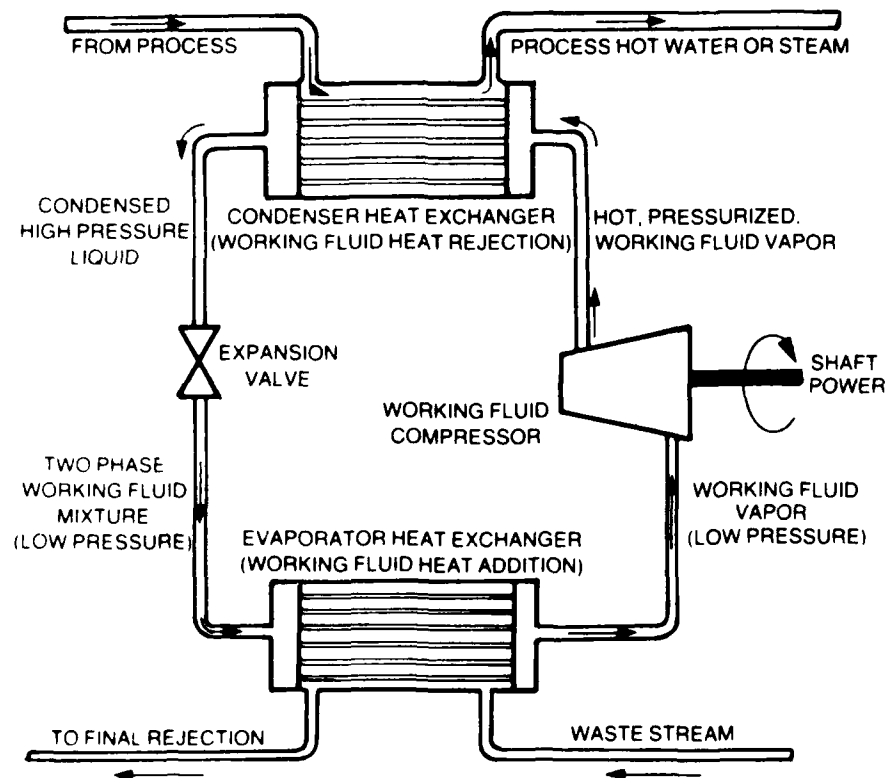


Figure 9. Closed-cycle heat pump schematic for waste heat recovery.

Table 2

Matrix of Typical Heat Recovery Technologies*

Heat Recovery Technology	Technical			Economics			Issues/Risks			Total	
	Problems	Benefits	Efficiency	Capital Cost	O & M Cost	Payback	Developed	Safe	Institutional		Wide Appl.
<u>Conventional</u>											
Plate-and-frame HX**	4	3	5	4	4	4	5	3	3	3	38
Air preheater	3	3	3	3	4	3	5	3	3	4	34
Waste heat boiler	4	3	4	2	4	2	5	3	3	3	33
<u>Somewhat Advanced</u>											
CHX on gas boiler or No. 2 oil boiler	5	3	4	4	4	4	5	4	3	5	41
CHX + economizer, gas	4	3	5	4	4	4	5	4	3	4	40
Other HX or economizer	4	3	4	4	4	3	4	3	3	3	35
Topping turbine	3	3	3	2	3	2	4	3	3	2	28
<u>More Advanced</u>											
CHX on No. 6 oil boiler	3	4	4	3	3	3	4	4	3	3	34
Small high-temperature recuperator	4	3	3	3	3	3	4	4	3	2	32
Industrial heat pump	3	3	3	3	3	3	3	4	3	2	30
CHX on coal boiler or incinerator	2	4	3	3	2	3	3	3	3	3	29
Organic rankine cycle engine	2	2	2	2	2	2	3	3	3	1	22

*Rated on a scale of 1 to 5, with 5 the best case, 1 the poorest case.

**HX = heat exchanger; CHX = condensing heat exchanger.

3 CASE STUDY: HEAT EXCHANGER FOR HOT SLURRY

Preliminary Evaluations

RAAP is a major AMC facility. It has several large unit operations, including nitric and sulfuric acid (NAC/SAC) production, a TNT manufacturing facility, and nitrocellulose (NC) production lines. The principal fuel for the two powerhouses is bituminous coal and the thermal energy requirements are approximately 1 percent of the total industrial energy supplied to New York State.

The site was visited to learn more about the major plant operations and energy consumption patterns, and to begin to identify potential heat recovery opportunities suitable for this program. Comprehensive tours and detailed assessments covered the NAC/SAC facility, the NC poaching and boiling tub operations, the waste propellant incinerators, and the high-pressure steam lines. Gas analysis and temperature monitoring equipment were used to measure available heat in flue gas streams, close energy balances, and determine the operating parameters for the powerhouses.

An initial list of likely RAAP waste heat recovery projects was developed:

1. Waste propellant incinerator
2. Powerhouse no. 1 condensing heat exchanger
3. Powerhouse no. 2 condensing heat exchanger
4. TNT spent acid recovery heat exchanger
5. Boiling tub house heat pump
6. NAC/SAC organic rankine-cycle engine
7. Topping turbine
8. NAC/SAC open-cycle heat pump
9. Poaching tub house heat recovery.

However, three of these options were eliminated during further evaluation, as summarized below.

TNT spent acid recovery: although installation of a corrosion-resistant pyrex heat exchanger has merit as a heat recovery option, the TNT processing line is scheduled to close soon.

Closed-cycle heat pump at the NC boiling tub house: a closed-cycle heat pump might further boost temperatures of batches of wash water leaving a heat recovery heat exchanger before they are used in the boiling tubs. A payback of 2.5 years would result from a continuous duty cycle, but batch operations would reduce the duty cycle and extend the payback period. This, coupled with the fact that extensive application engineering often is required for heat pump installation, led to elimination of this option.

ORC engine at NAC/SAC: the project would use an existing heat sink and source. With savings estimated at \$26,000 and an installed equipment cost of \$140,000, the simple payback exceeds 5 years.

Matrix Analysis and Project Selection

Six RAAP waste heat recovery projects now remained for further technical and economic assessment involving preliminary system analysis and design. The projects are listed in order of simple payback (best to worst), as estimated at this point in the study:

1. Powerhouse no. 1 condensing heat exchanger
2. Powerhouse no. 2 condensing heat exchanger
3. Waste propellant incinerator
4. Topping turbine
5. Poaching tub house heat recovery
6. NAC/SAC open-cycle heat pump.

Table 3 lists the results of a more detailed matrix evaluation for these technologies. The individual projects are now ranked in terms of site-specific criteria. Also in this table are rough estimates of the installed cost for each heat recovery system.

Based on the matrix scoring, three projects were selected as offering the greatest potential for heat recovery:

1. Nitrocellulose poaching tub heat recovery, score = 38-39
2. NAC/SAC open-cycle heat pump, score = 34-35
3. Powerhouse no. 2 condensing heat exchanger, score = 32.

After further review, the heat pump was eliminated from further consideration. Industrial heat pumps, whether open- or closed-cycle, have less demonstrated acceptance and reliability for this application and often require extensive engineering. Hence, the risk was greater than those associated with other options.

Thus, two projects remained, each of which appeared to be feasible and to offer good payback periods with respect to the initial investment: NC poaching tub heat recovery and powerhouse no. 2 condensing heat exchanger. The detailed technical and economic evaluation for the NC poaching tub is summarized below to demonstrate the procedures used.

Proposed Poaching Tub Heat Recovery System

A large amount of thermal energy is held in the tubs of heated nitrocellulose (NC or gun cotton) slurry, at RAAP. A heat exchanger could be used to recover a portion of this heat, which is now wasted as water is filled and emptied during the several processing steps. As one tub is emptied, a heat exchanger could transfer part of the heat to

another tub being filled. A heat exchanger must be selected that will not become plugged or blocked with the potentially explosive slurry.

The proposed project is to recover heat from the poaching tub house operation. "Poaching" is the final step in the NC purification process. In this operation, a batch of finely divided NC slurry is sent to tubs which are 18 ft in diameter and over 12 ft high. Each batch of slurry consists of approximately 11,500 lb of NC and over 120,000 lb of water, yielding a slurry with a 7 to 10 percent solids content. This water/NC slurry mixture fills a tub to a height of approximately 8 ft. The slurry is brought to a boil four times during the poaching cycle. The entire poaching sequence takes between 20 and 24 hr. When poaching is completed, the NC slurry is screened and filtered as it exits the poaching tub house.

The objective of this project is to preheat the incoming (i.e., fill) NC slurry with the outgoing (i.e., drain) slurry from another tub. To achieve this heat transfer without using storage tanks, the draining of a particular tub must coincide with the filling of another. It is estimated that the poaching cycle is flexible enough to allow the scheduling of 3 to 5 daily coincident drain and fill periods.

The proposed poaching tub heat recovery system is designed for a single line or house. The heat exchanger is manifolded from the NC supply and discharge lines of a particular house as shown in Figure 10. During operation, the incoming NC slurry is redirected by control valves to the cold side of the heat exchanger. Simultaneously, poached NC available from a separate tub would be delivered to the hot side of the exchanger and thus transfer its heat to the "cold" slurry. Once the slurry streams have been pumped through the heat exchanger, they would be redirected to the original supply and discharge lines associated with normal operations. Thus, the poached slurry would continue on to the blending house while the newly heated slurry (nonpoached) would be sent to a poaching tub for purification.

Scheduling would be facilitated by a centralized control panel that would display the status of individual tubs within a given house. As tubs became ready to drain, a status light would be activated. The lights would be matched with separate indicators for NC slurry available from the supply point, and for output requirements, to indicate when the heat recovery event should occur.

Equipment

The proposed poaching tub heat recovery mechanism could be implemented using either a plate-and-frame or a spiral heat exchanger, both of which were described in Chapter 2. The plate-and-frame heat exchanger has the higher heat transfer effectiveness and is relatively low-cost. The spiral heat exchanger alternative is considerably more resistant to plugging but is three times more costly due to a lower heat transfer effectiveness.

Both spiral and plate-and-frame heat exchangers are standard industrial components and are offered in stainless steel by several manufacturers. Currently, the spiral design is used in a number of applications at RAAP. The lower cost plate-and-frame design has found common use in a variety of industrial liquid-liquid batch heat recovery systems (e.g., paper manufacturing plants). Relatively plug-resistant plate-and-frame heat exchangers are manufactured by G. E. A. Ahlborn of Germany, with spacings on the order of 5 to 8 mm for use in the sugar industry. However, the plate-and-frame device best suited to handle NC slurry is found in the paper industry, where these units are used with cellulose slurries.

To move NC product through the heat exchanger network, two centrifugal slurry pumps were selected. Five-inch-diameter Schedule 40 carbon steel pipe was specified for system piping and it is estimated that 700 ft of this piping will be necessary.

Issues and Risks: Safety, Reliability, and Maintainability

Several issues will impact the feasibility of heat recovery at a poaching tub house. In general, the reliability and life are proven for slurry applications of a heat exchanger, the associated piping, and controls. The main factors affecting poaching tub heat recovery are discussed below.

1. Product contamination. At present, both high and low NC grades are processed simultaneously in the poaching tub facility. The single heat exchanger design may pose a potential contamination threat. For example, if low-grade slurry were to foul heat exchanger surfaces, a high-grade material might be contaminated during transit through the same exchanger. The use of a water wash after slurry transfer (as is currently done at RAAP) would mitigate this concern. The turbulence of flow in a plate-and-frame heat exchanger should also reduce fouling.

2. Possible NC solids buildup within the heat exchanger. This buildup could potentially lead to exchanger plugging and O&M problems, as well as to an explosion hazard due to the presence of dry NC solids. This scenario, however, is considered unlikely because of the highly turbulent flow that tends to minimize fouling and stagnation zone formation.

3. Added water. During screening operations, cold, filtered water is added to the slurry to prevent the screen from blinding. Introduction of this water is assumed to have a negligible impact on the slurry stream's energy content.

4. Scheduling. As mentioned previously, successful heat recovery at the poaching house depends on the ability to match tub drain-fill events while meeting the demands of adjoining operations.

5. Partial poaching tub drain. A key assumption in this analysis is that the entire tub of NC slurry is drained and sent to blending operations. Often, only a portion of a given tub is drained. The frequency of this occurrence and whether at least two complete drains occur over the course of the day should be determined.

6. Temperature variations of the discharged NC slurry. For this analysis, the inlet temperature to the heat exchanger was assumed to be constant at 170°F during the entire 45-min drain period.

7. Poaching tub heat loss. As previously stated, current production rates result in poached NC slurry remaining in tubs for an average of 24 hr after cycle completion. Natural convection-induced heat loss effects are assumed to be negligible.

8. Heat exchanger capacitive effects. The impact of initial temperature transients must be determined.

Performance and Cost Estimates

Table 4 lists major cost factors. The methods used in developing this cost estimate follow standard industrial practice and account for uncertainty in materials, labor costs,

etc. Installation of the equipment is projected to cost approximately \$22,100 for either the spiral or plate-and-frame, consisting primarily of labor and markup. Thus, the total installed cost is estimated at \$83,700 and \$169,300, respectively, for plate-and-frame and spiral heat exchangers.

For equal tub fill and drain times of 0.75 hr, approximately 14 to 16×10^6 Btu/hr are transferred between streams. On a per-cycle basis, this rate translates into a recovery of nearly 11 to 12×10^6 Btu/cycle, with over 10,000 lb of steam saved for each operating poacher tub cycle. The overall performance associated with batch heat recovery at the poaching house depends on the number of daily cycles from which heat can be recovered. As can be seen in Table 5, the savings range from \$37,500/yr to \$64,800/yr, depending on whether three or five cycles are recovered per day.

If three drain cycles per day can be recovered, the heat recovery system is a worthwhile investment, with a payback period of approximately 2 to 4 years for the plate-and-frame or spiral exchangers, respectively, as shown in Table 6. Since it is reasonable to expect that heat would be recovered from three drain cycles per day yielding a payback period of between 2 and 4 years, it is recommended that this technology be implemented at RAAP.

Table 3

**Matrix of Selected Heat Recovery Technologies:
Radford Army Ammunition Plant***

Heat Recovery Technology	Technical			Economics			Issues/Risks			Total	Est'd Cost	
	Problems	Benefits	Efficiency	Capital Cost	O & M Cost	Payback	Developed	Safe	Institutional			Wide Appl.
<u>Conventional</u>												
NC poaching tub HX**	4-5	4	5	4	4	4	5	2	3	3	38-39	85-170
<u>Somewhat Advanced</u>												
Topping turbine	3	3-4	3	4	2-3	4-5	4-5	3	1	4	31-35	100
<u>More Advanced</u>												
NAC/SAC heat pump	3	3	4	4	2-3	4	3-4	4	2	4-5	34-35	60-80
PH 2, condensing HX on coal	3	4	4	3	3	3	3	3	2-3	4-5	32	80-100
PH 1, condensing HX on coal	1	3	5	1	2	5	1	3	1	5	27	750
Incinerator heat recovery	1	4	4	1	1	4	1	2	1	2	21	200

*Rated on a scale of 1 to 5, with 5 the best case and 1 the poorest.

**NC = nitrocellulose; HX = heat exchanger; NAC/SAC = nitric/sulfuric acid production; PH = powerhouse.

Table 4
Major Cost Factors for Poaching Tub Heat Recovery*

Item	Cost (\$1000)
700 ft of 5-in.-diameter Schedule-40 steel pipe	25.5
(2) 20-HP slurry pumps (including electric motors)	9.7
(2) 16 x 106 Btu/hr PF HX**	15.4 (PF)
(2) 14 x 106 Btu/hr S HX	or 90.0 (S)
Miscellaneous equipment	3.0
Contingency	8.0 (PF)
	or 19.0 (S)
Total equipment cost	61.6 (PF)
	or 147.2 (S)
Installation	22.1 (PF or S)
Total project cost	83.7 (PF)
	or 169.3 (S)

*Estimated for FY88.

**PF = plate-and-frame; HX = heat exchanger; S = spiral.

Table 5

**Parametric Evaluation of Heat Recovery System
Performance for Various Cycles/Day Recovered**

Number of Cycles Recovered per Day	Yearly Energy Savings		Savings** (\$1000)
	(Btu/yr)	(lbm steam/yr)*	
2	7.6×10^9	6.5×10^6	23.7
3	11.4×10^9	9.7×10^5	37.5
4	15.3×10^9	13.0×10^6	51.15
5	19.1×10^9	16.2×10^6	46.8

*Steam savings = (Btu/yr) \div 1175.9 Btu/lbm

**Assumes fuel and non-fuel O/M = \$3500/yr; Net savings = (Energy saving - O/M).

Table 6

Payback Periods for Poaching Tub Heat Exchanger

Number of Cycles Recovered per Day	Plate and Frame (years)	Spiral (years)
2	3.1	6.2
3	2.0	4.0
4	1.5	3.0
5	1.1	2.2

4 CASE STUDY: CONDENSING HEAT EXCHANGER ON A PACKAGED BOILER

Preliminary Evaluations

LAAP conducts major metal-working operations: forging, heat treating, and final machining of metal ammunition parts (Area Y, 155mm shells). Additional LAAP operations involve loading, assembling, and packing various munitions, as well as quality assurance testing. The principal fuel at LAAP is natural gas, most of which is employed in the direct heat processes associated with Area Y.

The site was visited as was done for RAAP. The initial list of LAAP heat recovery options is as follows:

1. Rotary hearth recuperator
2. Rotary hearth natural draft stack heat recovery
3. Area C or D: condensing heat exchanger
4. Oil incinerator heat recovery
5. Hardening/draw furnace heat recovery
6. Water spray cooler heat recovery.

Efforts were directed toward closing energy balances and determining the operational excess air levels for the rotary hearth furnace, oil incinerator, water spray cooler, rotary hearth furnace natural draft stack, and Area C boiler plant. Gas analysis and temperature monitoring equipment were brought to the site to determine available heat in flue gas streams. Table 7 summarizes the measurements.

In addition to the measurements, detailed assessments were made of unit operations associated with potential heat recovery applications. This information proved as important to the preliminary systems analysis and design as did the measured data. The assessments included a review of specific piping and installation diagrams for the liquid mover condensate return stations.

Matrix Analysis and Project Selection

The six LAAP waste heat recovery projects identified for further study are listed below in order of estimated simple payback (best to worst):

1. Rotary hearth recuperator
2. Oil incinerator heat recovery
3. Area C (slightly preferred to D) condensing heat exchanger
4. Water spray cooler heat recovery
5. Rotary hearth natural draft stack heat recovery

6. Hardening/draw furnace heat recovery.

Table 8 shows the results of the more detailed evaluation. Based on the matrix scoring, three projects were selected as offering the greatest potential for heat recovery:

1. Area C condensing heat exchanger, score = 42
2. Rotary hearth furnace recuperator, score = 33
3. Draw furnace oil incinerator, score = 31.

After further review, the draw furnace oil incinerator was eliminated from further consideration. The exhaust would contain corrosive flue gases that could damage ceramic and metallic recuperator systems, which results in a high risk for the project.

Thus, two projects remained for further study: the Area C condensing heat exchanger and the rotary hearth furnace recuperator. The condensing heat exchanger was selected for presentation in this report.

Process Description

Conventional design practice has required that exhaust flue gas be kept well above the dew point temperature because localized cooler spots must not experience acid condensation. However, a condensing heat exchanger (condensing HX) is now possible due to the development of equipment that uses materials with corrosion-resistant properties such as glass and Teflon® resin coatings. As the flue gas temperature is lowered below 200°F, a portion of the latent heat is recovered through local condensation.

The proposed project is to recover flue gas waste heat from a packaged boiler located at the Area C process facility at LAAP. The York Shipley firetube boiler has a nominal firing rate of 20.5 million Btu/hr. The boiler normally operates at partial capacity, and provides process steam for use in melting explosives and operating curing ovens to process explosive components. The boiler operates 7200 hr/year and, in 1985, consumed 26,670 million cu ft (mcf) of natural gas. The flue temperature is in the 350 to 375°F range. Currently, excess air levels at low loads are about 150 percent.

The boiler operates using 90 to 100 percent cold makeup water, with only 10 percent of the condensate returned to the boiler during the winter months. The system originally was designed to return 50 to 75 percent of the condensate from the plant area. Since the boiler is located at a distance from the explosive area, the distribution system consists of several thousand feet of steam piping. This arrangement has made condensate return difficult to implement; as a result, only condensate from the office building and the shower facility outside the explosive area are returned to the boiler.

At a nominal load condition (i.e., 7180 standard cu ft/hr [scfh] natural gas), less than 5 percent of the input energy or 0.26 million Btu/hr is used to preheat makeup water. The objective of this heat recovery project is to use the 350°F flue gas to preheat the makeup water, thereby reducing the steam load to the deaerator.

Proposed Heat Recovery System

The proposed system is a condensing HX for preheating boiler makeup water. General characteristics sought for this heat exchanger were:

1. Reduce flue gas from 350 to 150°F.
2. Preheat over 5000 lb/hr of water from 60 to 140°F (at nominal load).
3. Recover approximately 500,000 Btu/hr of sensible and latent heat.

Figure 11 portrays the modified process with a condensing HX unit in place, assuming 20 percent excess air and negligible condensate return. Note that water and flue gas temperatures will vary considerably, depending on operating conditions.

The exhaust gas from gas-fired boilers becomes corrosive when flue temperatures are reduced below 200°F. Accordingly, conventional economizers used for waste heat recovery have encountered problems, requiring frequent replacement of corroded metallic surfaces. Corrosion is most severe upon cold start-up when the boiler is turned on after being shut down for maintenance or during an off-shift. Condensing HX technology has mitigated the problem of corrosive flue gas.

Figure 12 shows a packaged condensing HX system. The heat exchanger is a conventional shell-and-tube design with the flue gas passing through the shell side and the water flowing through the tubes. The heat exchanger is constructed with plastic shells, tubing, or liners on the flue gas side to protect metallic surfaces from the corrosive flue gas. These corrosion-resistant heat exchangers permit additional extraction of sensible heat from the flue gas. Furthermore, when the flue gas is lowered below 200°F, some of the latent heat of combustion water can be recovered.

The proposal is to install equipment manufactured by Condensing Heat Exchanger (CHX®) Corporation of Latham, NY, which has been developed and tested with the support of Brookhaven National Laboratory. The unit is a Teflon®-lined heat exchanger designed as a retrofit device for recovering heat from low-temperature boiler flue gas.

The innovative characteristic of the proposed equipment is the use of the Teflon fluorocarbon resins to protect metallic surfaces from the corrosive flue gas. CHX Corporation has developed a manufacturing system enabling all heat exchanger surfaces that come into contact with exhaust gas to be protected with Teflon. In addition, the inclusion of dynamic Teflon-to-Teflon seals in the shell-and-tube penetration assembly allows for mechanical and thermodynamic conditions to be satisfied during the exhaust gases' transit through the heat exchanger. The gases are then directed through a Teflon-covered exhaust plenum to a fiberglass stack for ultimate discharge to the atmosphere. Both materials have proven resistant to acid flue gas and acid condensate over 6 years of service.

The heat exchanger consists of five individual modules in series and is 8 ft high by 5 ft deep by 4.9 ft wide. The exchanger weighs 2875 lb empty and 3625 lb when flooded with water. The total heat exchange surface area is 515 sq ft. There are three water manifold inlets at the base of the unit and the design water flow is 35 gpm. As previously stated, the specified heat exchanger can handle all load conditions experienced by the boiler. The system requires its own stack, made of fiberglass, with a recommended diameter of 20 in. Table 9 lists design specifications for the condensing HX when the boiler is firing at 7180 scfh.

Equipment Manufacturers and Field Experience

In the United States, CHX Corporation has by far the most field experience with condensing HXs and has installed over 60 systems in boiler applications. The first unit installed has now been in operation for more than 6 yr. The simplicity of design and operation have been credited with giving the system a high reliability.

Two other U.S. companies, Corning and Beltran, have had limited experience with condensing HX systems for boiler operations. Corning Glass Works of Corning Processed Systems, Big Flats, NY, manufactures a pyrex condensing unit called the Cortherm. The pyrex heat transfer surface has almost universal resistance to chemical attack, high thermal shock resistance, and an overall heat transfer coefficient equivalent to that of a metal tube system. The pyrex heat exchanger was designed primarily for spray dryers and other gas heat transfer applications; Corning recently has begun making units for boiler heat recovery in which makeup water is preheated with flue gas.

Beltran Company of Brooklyn, NY, has custom-made condensing units using protective coatings and liners; however, there is no formal product line. Two more companies, North American and Cannon Boiler Works, have sold heat exchangers with protective coatings, but these units have not demonstrated corrosion resistance in the field.

Outside the United States, condensing HX units made of stainless steel are manufactured by Fagerstar in Sweden and Froling Reatherm in Germany. Corrosion-resistant heat exchangers made of copper/aluminum are manufactured by Zantingh in Germany, while designs using glass tubes are marketed by Air Frohlich in Germany and Serausson in France.

Issues and Risks: Reliability and Life Expectancy

The heat exchanger made by CHX Corporation has shown remarkable performance with no failures attributed to the handling of flue gases. According to the manufacturer, downtime on the installed systems has been minimal, for a system reliability better than 99 percent. Preventive maintenance requirements are standard and include work such as fan belt tightening, lubrication, and general cleaning.

The life expectancy is likely to be limited by tube-side corrosion rather than degradation of the heat exchanger's shell side. Compatibility of water with the tube materials is a more important consideration than are flue gases on the shell side. A life expectancy of 10 years seems possible, which is quite reasonable for this equipment.

Payback Estimates

Table 9 summarizes heat exchanger performance estimates for the condensing HX unit. The heat exchanger will process all flue gas entering at 350°F. This gas will be heat-exchanged with 11.4 gpm of makeup water, thereby reducing the bulk gas temperature from 350 to 155°F, while heating the makeup water from 60 to 140°F. There will be a total heat recovery of 470,000 Btu/hr, yielding a savings of \$17,600/yr. This performance estimate assumes 20 percent excess air and no condensate return.

The estimates are based on CHX Corporation Model 96-48-DW5, to be installed during FY87 adjacent to the boiler house and connected to the existing stack. The heat exchanger system costs (FOB NY) \$37,180, not including the fiberglass stack (\$60/ft) and

the installation fee. The estimated additional costs (service, installation, and stack) total \$23,315, for an overall project cost estimated at \$63,000.

For the Area C boiler at LAAP, future energy savings will depend on the level of condensate return and excess air control. Assuming service to the fuel/air linkage is performed when required, estimated energy savings are approximately \$17,600/yr. The payback period for the investment, based on the predicted energy savings, is 3.6 yr. (This estimate of simple payback does not consider possible increases in O&M costs.) It is also estimated that the unit will provide enough extra capacity to handle occasional extreme winter peak steam loads. Also, additional future hot water loads have been identified, which will further improve system economics.

Table 7
Summary of Measurements at Louisiana
Army Ammunition Plant

	CO ₂ (%)	O ₂ (%)	Flue Temp. (°F)	Firing Rate (pph)	Excess Air (%)	Remarks
Area C boiler	8.4	8.0	380	15000	55	Full load tests: makeup water = 100% at 5-30 gpm, depending on load
RHF recuperator exhaust	5.6	12.5	905	16490	130	Enough heat available; still present in exhaust
Oil incinerator	6.5	14.0	1130	(15000)*	180	Distinct potential for heat recovery; potentially corrosive conditions
Water spray cooler	0.7	20.0	341	(15000)*	>1000	Excessive dilution observed
RHF natural draft stack	2.7	18.0	750 -1000	16490	300	Door replacement must be examined
Hardening furnace	0.2	~21.0	185	(15000)*	>1000	Excessive dilution observed

*Note: a single gas meter monitors the collective fuel flow to the incinerator, the water spray cooler, and the hardening furnace.

Table 8

**Matrix of Selected Heat Recovery Technologies :
Louisiana Army Ammunition Plant***

Heat Recovery Technology	Technical			Economics			Issues/Risks			Total	Est'd Cost	
	Problems	Benefits	Efficiency	Capital Cost	O & M Cost	Payback	Developed	Safe	Institutional			Wide Appl.
<u>Conventional</u>												
None selected												
<u>Somewhat Advanced</u>												
Area C CHA on gas boiler**	5	3	5	4	4	4	5	4	3	5	42	70-100
Draw furnace oil incinerator	2	4	3	2	3	3-2	4	3	2	1	31	50-70
Hardening furnace	2	1	3	2	3	1	3	3	1	2	21	-
<u>More Advanced</u>												
RHF secondary recuperator	4	2	5	3	3	3	4	4	3	2	33	50-80
RHF replace recuperator	1	2	4	4	4-2	5	2	4	3	2	31	200-250
RHF natural draft recuperator cooler	3	2	2	2	2	3-2	4	3	2	3	25-26	250-280

*Rated on a scale from 1 to 5, with 5 being the best case and 1 the poorest.

**CHX = condensing heat exchanger; RHF = rotary hearth furnace.

Table 9

Condensing Heat Exchanger Specifications
and Predicted Performance

Boiler firing rate (nominal load)	7,180 scfh
Flue gas mass flow @ HX inlet	6,525 lb/hr
Flue gas flow @ HX inlet	2,205 acfm
Flue gas inlet temp.	350°F
Flue gas outlet temp.	155°F
Water flow through HX	11.4 gpm
Water inlet temp.	60°F
Water outlet temp.	140°F
Sensible heat recovery	427,700 Btu/hr
Latent heat recovery	42,300 Btu/hr
Total heat recovery	470,000 Btu/hr
Projected energy savings (1987 dollars)	\$17,600/yr*

*Savings are predicted for times during which the boiler is firing at 7180 scfh.

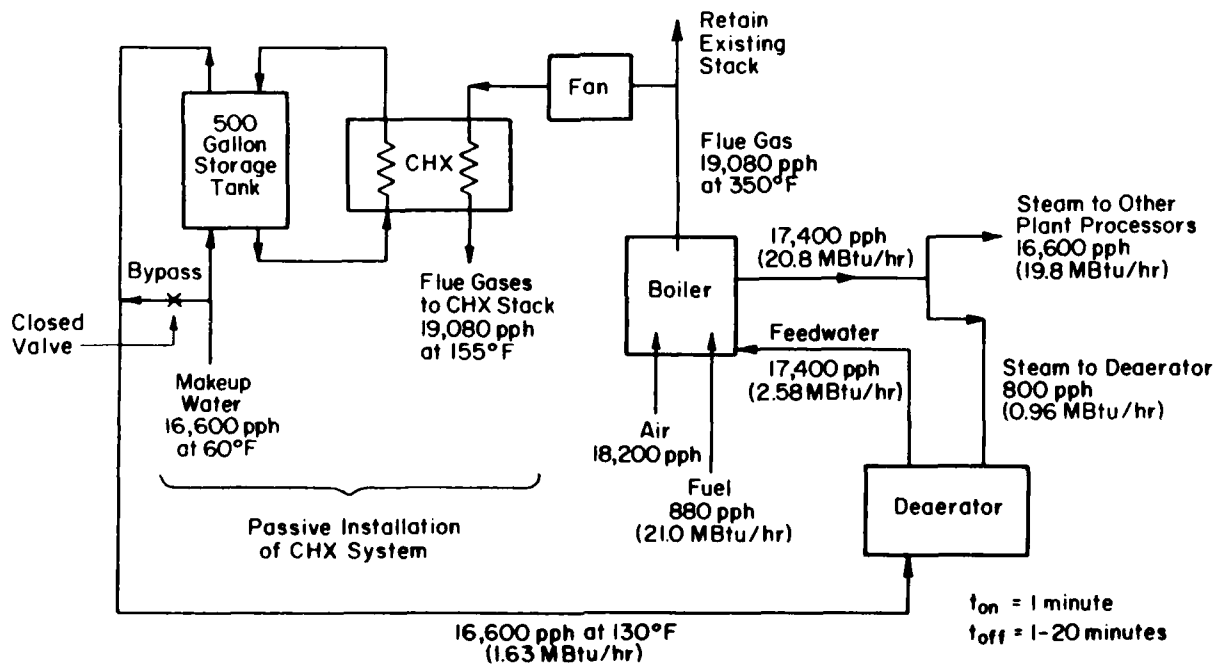


Figure 11. Proposed waste heat recovery with condensing heat exchanger.

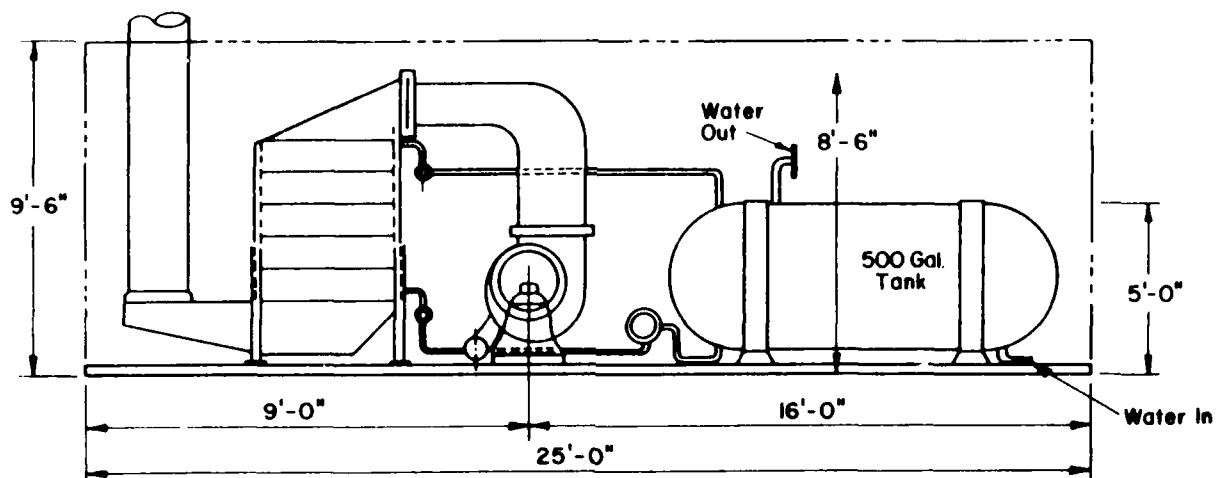


Figure 12. Packaged condensing heat exchanger system.

5 CONCLUSION

An initial study has been completed to identify opportunities for using waste heat recovery techniques at AMC facilities. In this first phase, potential applications were listed for two Army ammunition plants--RAAP and LAAP. These possibilities were evaluated from a pro-and-con standpoint and the results tabulated in matrix form. Based on this assessment, some systems were selected for further study whereas others were eliminated from consideration.

Next, comprehensive energy studies were conducted at the plants to determine actual conditions under which the proposed techniques would need to perform. Preliminary designs were developed for the most promising systems, after which a more detailed evaluation was carried out, including an economic analysis.

Two case studies have been presented to demonstrate the project evaluation and selection process. One project was a heat exchanger for hot slurries at RAAP and the other involved a condensing heat exchanger for a packaged boiler at LAAP.

As this study continues, additional AMC sites will be selected for the evaluation process in order to identify other opportunities for using the different heat recovery technologies. The intention is to field-test a variety of heat recovery applications to gain wider experience and understanding of the systems' performance characteristics. After these systems have been placed in service for the tests, the performance of each unit will be verified through continued monitoring and analysis. The first unit to be tested will be the condensing heat exchanger at LAAP; a condensing HX was installed during FY87 as a turnkey project.

METRIC CONVERSIONS

1 mile	= 1.6 km
1 ft	= 0.305 m
1 lb	= 0.454 kg
1 Btu/hr	= 0.293 W
1 Btu	= 1055 J
1 cu ft	= 0.0283 m ³
1 lb/sq in.	= 6895 Pa
1 gal (U.S. Liquid)	= 3.78 x 10 ⁻³ m ³
(°F - 32)/1.8	= °C

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ATTN: SMCMS-EN 39468
ATTN: SMCNE-EN 47966
ATTN: SMC PB-FEN 71602
ATTN: SMCRA-OR 24141
ATTN: SMCRI-DLP 61299
ATTN: SMC RV-CR 44266
ATTN: SMC RB-OR 95367
ATTN: SMCSC-EN 18505
ATTN: SMCSL-CR 63120
ATTN: SMCSU-OR 66018
ATTN: SMCTC-EN 55112
ATTN: SMCVO-CR 37422
ATTN: SMC RM- ISF-Q 80022
ATTN: SMC WV-EH 12189

HQ, DESCOM AMSDS-EN-FO 17201 (2)

DESCOM
ATTN: SDSAN-DEL-FE 36201
ATTN: SDS CC-EFA 78419
ATTN: SDSTE-FW-CO 87301
ATTN: SDSLE-EH 17201
ATTN: SDSLB-ASF-E 40511
ATTN: SDSNC-EF 17070

ATTN: SDSTE-PUI-F 81601
ATTN: SDSRR-GU 75507
ATTN: SDSLE-VA 61074
ATTN: SDSSA-EL-1 95813
ATTN: SDSSE-H 14541
ATTN: SDSSH-EE 95331
ATTN: SDSSI-DEH 96113
ATTN: SDSTO-EH-O 18466
ATTN: SDSTE-ELF 84074
ATTN: SDSTE-UAA-F 97838

HQ, TECOM
ATTN: AMSTE-LG-F 21005

TECOM
ATTN: STEAP-FE-U 21005
ATTN: STEDP-FS-E 84002
ATTN: STEJP-EH-E 47250
ATTN: STEWS-IS-EN 88002
ATTN: STEYP-EH-P 85365
ATTN: STRNC-DF 01760

HQ, TACOM
ATTN: AMSTA-XEE 48397

TACOM
ATTN: AMSTA-CWP 48397
ATTN: AMSTA-CLPF 45804

HQ, AVSCOM
ATTN: SAVAI-F 63120

AVSCOM
ATTN: SAVAS-Z 62040
ATTN: DCASPRO NY-RAA 06497

HQ, CECOM
ATTN: SELHI-EH-EV 07703

CECOM
ATTN: SEHVH-EH-EE 22186

HQ, LABCOM
ATTN: AMSLC-IS 20783

LABCOM
ATTN: SLCHD-FE-A 20873
ATTN: SLCMT-TR 02172

HQ, MICOM
ATTN: AMSMI-RA-EH-MP 35898

Defense Technical Info. Center 22314
ATTN: DDA (2)

END

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